Using Technology and Integrated System Design to Address Disaster Management in the State of Texas

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Abstract- This research paper presents a comprehensive approach to disaster management, with a specific focus on preparedness for natural disasters in Texas. The study emphasizes the importance of early warning systems, utilizing advanced technologies like high-resolution satellite imagery and remote sensing data for effective disaster monitoring and response. The proposed integrated disaster management system is designed to enhance the resilience of communities through improved risk awareness, hazard monitoring, and efficient information dissemination. The system integrates several components, including mitigation and prevention, addressing residual risk, and preparedness, to ensure a coordinated and rapid response to natural disasters. This approach aims to minimize loss of life and property by enabling better planning and preparedness at both governmental and community levels.

***Index Terms*-** Disaster Management, Early Warning Systems, High-Resolution Satellite Imagery, Preparedness and Response, Remote Sensing Data.

I. Introduction

According to Srikanto's report on "Analysis of Damage Caused by Hydrometeorological Disasters in Texas." Both the frequency of natural catastrophes and the harm they cause have been on the rise over the past several decades. The number of natural catastrophic occurrences has grown, from 730 events ($103 billion) in 2015 to 750 events ($175 billion) in 2016 based on the two most recent years of research. Texas had hydrometeorological catastrophes that resulted in $54.2 billion in property damages between 1960 and 2016, with hurricanes, tropical storms, and hail being the main culprits at 56% of the total damages, followed by flooding and severe thunderstorms at 24% [1].

From the statistics provided above, Texas has been confirmed as a city that has experienced a lot of natural disasters, hence the need for the design of a robust and resilient integrated system that could be used to manage disaster awareness, preparedness, and recovery. There are six standard ways in which we can implement an integrated approach to disaster management occasioned by natural disasters in any city, town, state, or country. They include Early warning, Prevention, addressing residual risk, Preparedness, Responding, and Recovery.

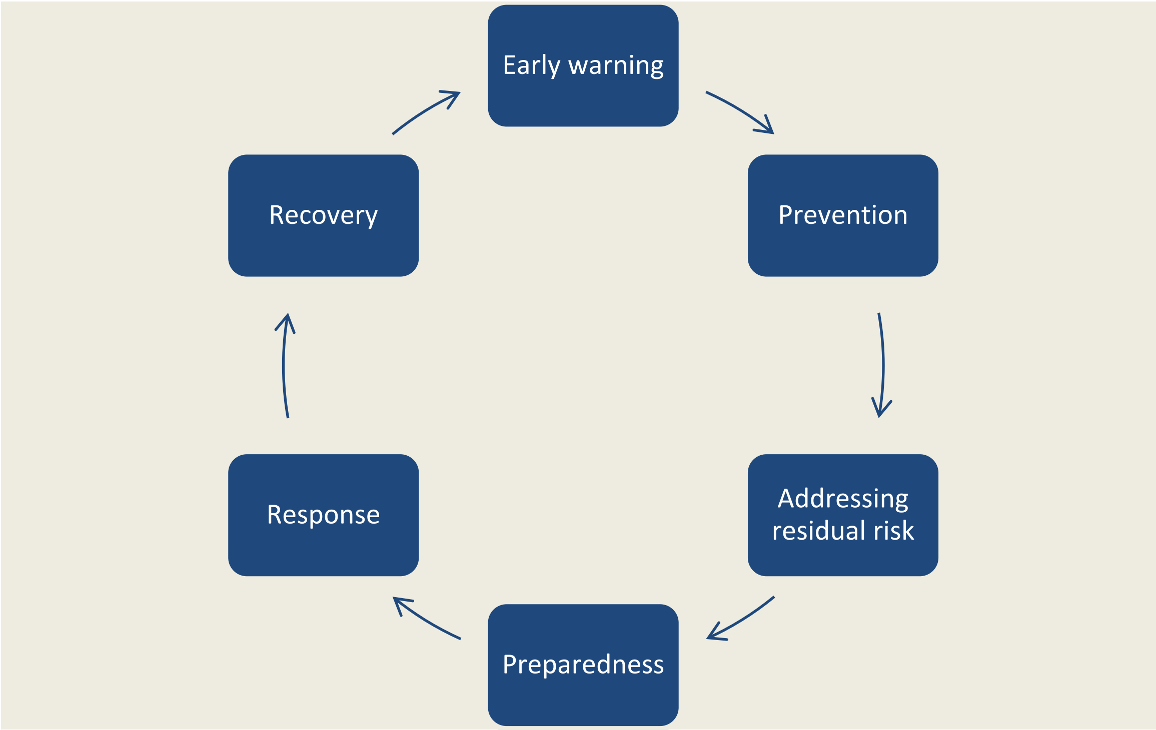

Figure 1: Integrated Approach to Disaster management

This research shall regroup the six into three main areas which shall include:

1. Disaster awareness
2. Preparedness
3. Recovery

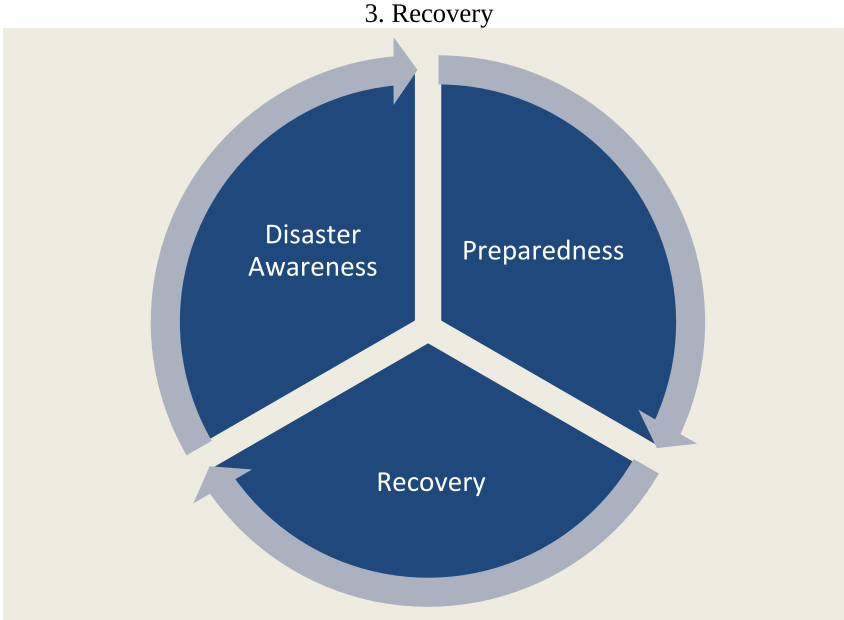

Figure 2: Integrated Approach to Disaster management in three categories

This study shall focus on the Preparedness segment of disaster management because if there is an effective and efficient way of identifying when natural disasters are about to occur, persons involved can easily be prepared either to mitigate or relocate to a safer environment pending the duration of the disaster. The Government and other Governmental agencies and organizations will be better prepared and equipped to either mitigate or respond effectively and adequately to the natural disaster.

II. Research Elaborations

Chapter 2 - System Components

Early warning:

The component of focus in our design is early warning and according to National Institute of Disaster management New Delhi publication, Early warning can be defined as a collection of capabilities known as an Early Warning System (EWS) that is required to produce and communicate timely and accurate warning information about potential severe occurrences or catastrophes (such as floods, drought, fire, earthquakes, and tsunamis) that pose a hazard to human life. This information's objective is to empower those who are threatened to respond effectively and quickly to lessen the likelihood of danger, loss, or risk by enabling them to plan ahead and take the necessary precautions. According to the same article, there are four main elements that are involved in the early warning, and they include the following:

1. *Risk awareness:* Risk assessment offers crucial data to establish priorities for mitigation and preventative methods as well as early warning systems design.
2. *Monitoring and Predicting:* Systems with monitoring and forecasting capabilities offer prompt assessments of the possible risk posed to societies, economies, and the environment.
3. *Information dissemination:* To inform local and regional governmental organizations, communication systems are required to provide warning messages to the places that may be impacted. For the public and authorities to understand the communications, they must be trustworthy, synthetic, and straightforward.
4. *Reaction:* The main components of an efficient early warning system are coordination, excellent governance, and adequate response plans. In order to mitigate disasters, it is crucial to raise public awareness and educate the public [[i]].

Early warning is an item in the Preparedness component of the Design as shown in figure 3 below.

Prevention:

According to Queensland Fire and Emergency Guideline, Preventative measures lessen the likelihood of a disaster event happening or the severity of an event, should it occur, in accordance with the guiding principles of the Act. Mitigation is defined as actions taken in advance of a disaster with the intention of lessening or eliminating its effects on society and the environment, while prevention is defined as regulatory and physical measures to ensure that emergencies are prevented, or their effects are mitigated.
Communities will be safer, more resilient, and sustainable if proactive, focused preventative and mitigation policies are put in place to address anticipated risk factors, threats to general population, and decrease or eliminate the potential impact of disasters. All individuals must share responsibilities for a community to be ready and resilient. Proactive planning and preparation for the protection of people, property, and the environment through knowledge of hazards, associated risks, and local disaster management arrangements considerably increase disaster resilience [[ii]].

Addressing Residual Risk:

Based on the information available from United Nations Office for Disaster risk reduction, residual risk is said to be available even with successful disaster risk reduction strategies in place. As expected, risk can never be zero, therefore there will always be a residual risk, which necessitates maintaining emergency response and recovery capabilities. The existence of residual risk suggests that effective emergency services, preparedness, response, and recovery capacities, along with socioeconomic policies like safety nets and risk transfer mechanisms, continue to be needed to be developed and supported as part of a comprehensive approach [[iii]].

Preparedness:

European Civil Protection and Humanitarian Aid Operations in their article said all series of actions taken by governments, organizations, communities, or people to better respond to and handle the immediate aftermath of a disaster, whether it be man-made or brought on by natural hazards, is referred to as disaster preparedness. The goal is to minimize the loss of life and livelihood. Simple actions like preparing for search and rescue missions, establishing early warning systems, creating contingency plans, or stockpiling supplies and equipment can have a big impact. In order to increase a community's resilience, disaster preparedness is crucial.

A growing number of people and assets are vulnerable to disasters as a result of population increase, rapid and unplanned urbanization, climate change, environmental degradation, and pervasive poverty. Additionally, a lot of these events take place in unstable and war-affected regions, adding to the complexity of crises and burdening nations with violent conflict or unstable governments.

The ability of nations and communities to lessen the effects of disasters is strengthened through better practice and response procedures, which also save lives. It is easier to be more prepared when one is aware of the likelihood and frequency of natural hazards as well as their dangers, weaknesses, and potential effects on people and property. International efforts should support governments and communities in recognizing threats and developing preparedness capacities for preventive and early action rather than merely providing emergency reactions. Disaster preparedness is economical and saves money for relief [[iv]].

Response:

Bexar County Emergency Management explained response to disaster management to mean the whole strategy used in the coordination and management of resources (including personnel, equipment, and supplies) during a response, as well as actions taken to ensure the safety of people, property, and the environment. The response phase comes into play when a major catastrophe or disaster occurs [[v]].

Recovery:

Upstate Medical University in her article explained while the recovery is very important by saying that restoring the afflicted area to its prior state is the goal of the recovery phase. Recovery activities are concerned with challenges and choices that must be made after urgent needs have been met, which sets them apart from the Response phase in that regard. Reconstruction of devastated property, employment opportunities, the repair of other critical infrastructure, and the reopening of critical services are the main focus of recovery activities.

Recovery operations are a crucial stage in the emergency management process, yet they are frequently disregarded. The Recovery phase will be carried out by a well-trained and prepared team [vi].

III. Design

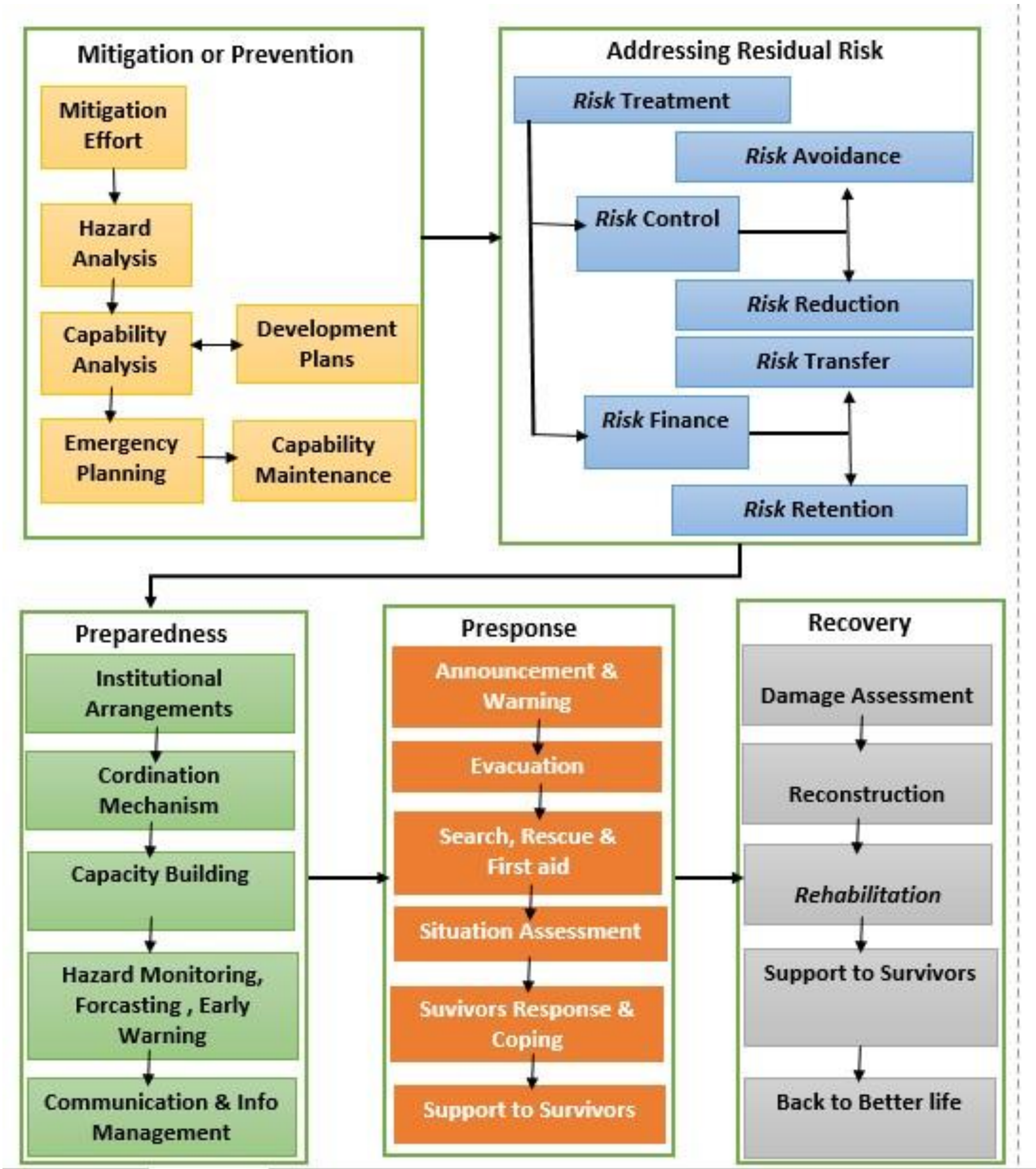

Figure 3: Integrated system Design Model for Disaster management

The five components that make up the Integrated system Design Model for Disaster management shall be discussed in detail.

Component 1: Mitigation and Prevention

There are six blocks that make up this component and their details are discussed below

Mitigation Effort:

The method or outcome that lessens the severity, danger, suffering, harshness, or damage of something.

Hazard Analysis:
The procedure of gathering and analyzing data on risks and the circumstances that led to their presence to determine which are important for safety and others that should be addressed accordingly. Risk Matrix is the tool that will be used to perform the hazard analysis.
Capability Assessment:
The term "capability assessment" refers to a review to determine whether the Mutual Obligation Requirements included in the Participant's Job Plan are reasonable given the Participant's circumstances and whether the Participant is capable of meeting them.
Development Plans:
A local authority's policies and suggestions for the use of land in its jurisdiction are outlined in a development plan. In the UK, the phrase is frequently used. One kind of development plan is the local plan [vii].
Emergency Planning:
Procedures for handling urgent or unforeseen events are laid forth in an emergency plan. Being ready will allow us to prevent fatalities and injuries. Reduce the amount of stock, equipment, and building damage, safeguarding the environment and the neighborhood [viii].
Capability Maintenance:
Plans, facilities, finances, personnel, spare parts, technical data, test equipment, tools identified as available resources for required maintenance tasks [ix].

Component 2: Addressing Residual Risk

The component 2 is focusing on risk that might still exist despite all effort and activities that have been done in component 1 to mitigate or prevent disasters from happening. There are two major ways of addressing the issue and that include risk control and risk financing.

The risk control includes all part of the risk management process in which methods to neutralize or reduce the identified risks are implemented. The actions taken in this stage include the following: Relocation, Regulation of land use, Retrofitting of buildings, Reliable Drainage System and Emergency drills.

The second way of addressing the issue is through risk financing activities such as Insurance, Catastrophe bond, Disaster fund and Self-insurance.

Component 3: Preparedness

This is the component of our emphasis, it contains five blocks and the activities of these five blocks will determine to a great extent the effect natural disasters like flood, hurricane, tornadoes will have when they finally occur in Texas.

Institutional Arrangements: The state of Texas is vulnerable to countless natural disasters such as hurricanes, tornadoes, floods, and wildfires. These negatively affect its residents and have significant financial impacts from minor repairs to loss of life. When damage is widespread, the most practical solution may be to publicly purchase private property. This summary highlights the economic and public policy impacts of Texas municipalities purchasing properties from residents living in areas damaged repeatedly by natural disasters. The U.S. government launched several home-buying programs in the 1990s. Since then, Texas has received more federal disaster relief grants than any other state in the United States. Only In 2019 alone, 14 natural disasters in the United States caused more than $1 billion in damage, with seven of those disasters affecting Texas [x] These and similar actions are what we refer to Institutional arrangements.

Coordination Mechanism: Emergency management coordination includes cooperation between transportation authorities, transit providers, emergency managers, and incident responders during major regional natural disasters. These actions and activities are already planned out before the occurrence of any disaster either natural or manmade.

Capacity Building: This is an ongoing process that enables managers, stakeholders, and the community to better perform their functions during a crisis/disaster through extensive training and retraining of all stakeholders [xi].

Hazard Monitoring, Forecasting and Early warning: Satellite Imagery and Geographic Information Systems (GIS) and Maps can provide emergency and disaster response, managers with a wealth of information to assess, analyze, and monitor natural disasters such as hurricanes, tornadoes, volcanoes, earthquakes, and damage caused by tornadoes in large and small areas of the world. Remote sensing satellite image data is an important tool and technology used for disaster monitoring and management to create models for strategic planning and to predict and control disasters as they occur. Estimates of specific cover layers likely to be flooded by a disaster can enable operators and planners to better assess the risk and vulnerability of their area. This information will help prioritize targeted mitigation and preparedness activities for their area. The use of multi-dimensional satellite imagery is essential to separate the constituent elements of satellite maps and to interpret damage images for pre- or post-disaster assessment.

Communication and Information Management: It goes without saying that efficient information management and communication are essential to successfully managing and lowering disaster risk. This research work emphasis on communication and information management during the emergency preparedness and response phases. The various social media platforms shall be used as a means of disseminating crucial information before and after natural disasters as well as special announcement for the distribution of relief materials after a disaster has occurred.

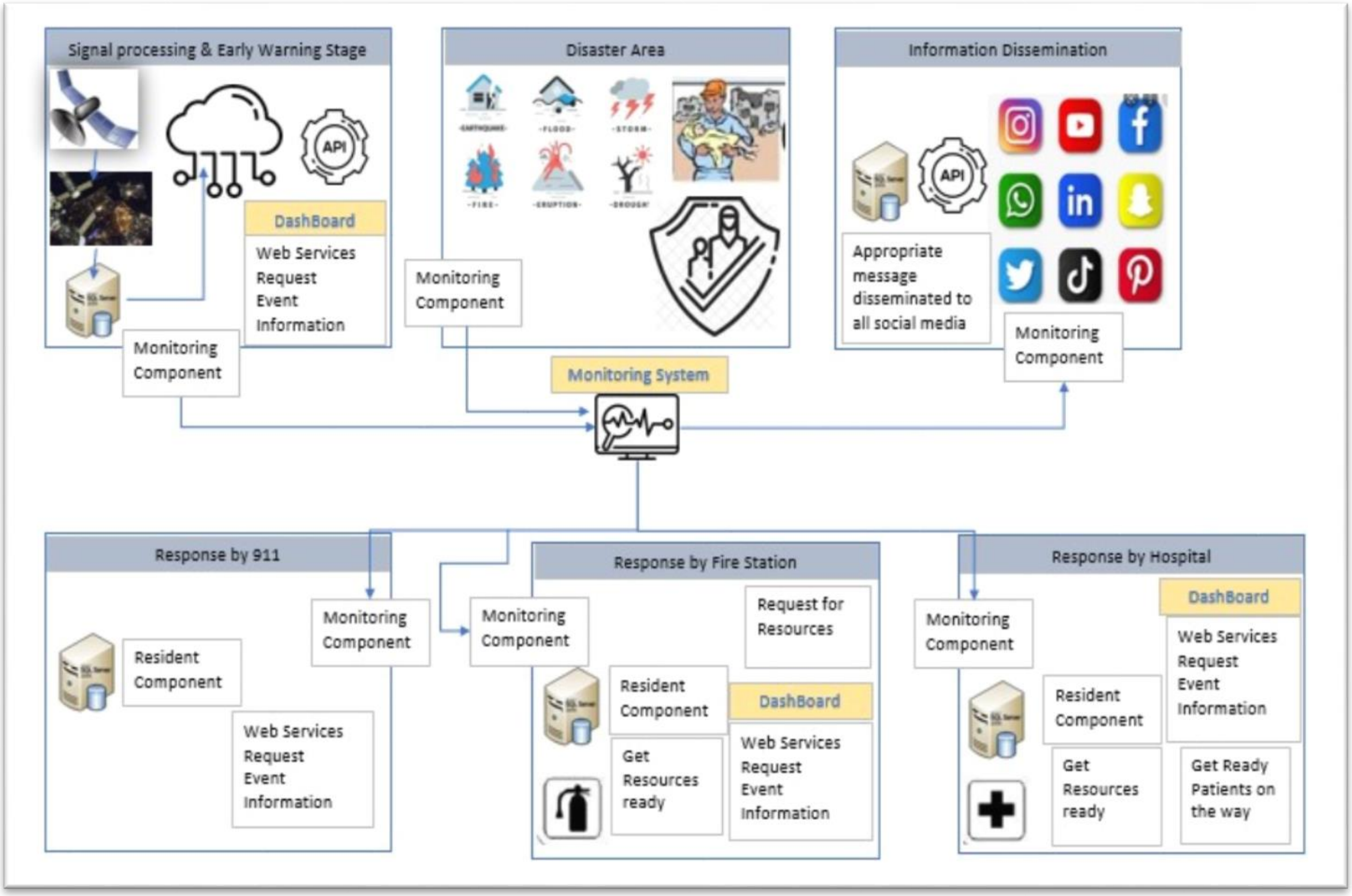

Figure 4: The Design of Comprehensive Disaster Management System

Findings: Implementation Details of the Comprehensive Disaster Management System

Signal Processing and Early Warning Stage

High Resolution Satellite image capturing: It's impossible to avoid viewpoint when you're 22,000 miles away. Nearly three times the diameter of the planet itself away, Earth appears to be a vast organic system that is always in motion when viewed from that altitude. Three times more than its predecessor, the Himawari-8 weather satellite now captures 144 images of the entire planet each day. The pictures demonstrate the development of weather systems and aid in the development of more accurate models of the atmosphere on Earth. The satellite has double the resolution of comparable weather satellites that monitor other regions of the world and can detect details as small as a third of a mile.

A similar cutting-edge weather satellite, GOES-R, was launched by National Oceanic and Atmospheric Administration (NOAA) and National Aeronautics and Space Administration (NASA) early this year 2022. The satellite follows weather systems heading toward the United States as they pass over either the eastern Pacific or the Caribbean [xii].

Applications of Satellite Imagery & Remote Sensing Data: In order to monitor several applications including image fusion, change detection, and land cover categorization, remote sensing data is essential. A crucial method for obtaining data on the resources and environment of the earth is remote sensing. The widespread use of satellite imaging data has been greatly aided by features like "Street View" on numerous mapping apps like Google Earth and Bing Maps as well as the availability of high-resolution satellite photos.
Spectral, geographical, and temporal resolutions are all included in remotely sensed satellite images and data. The capacity of a sensor to specify precise wavelength intervals is known as spectral resolution, and it incorporates aspects of remotely sensed picture classification. One of the key factors affecting the accuracy of ground objects is spatial resolution, which determines the size of an object that can be seen clearly on an image. Temporal resolution, which is used to create land cover maps for urban planning, detecting changes in land use, and transportation and environmental planning, can be described as the amount of time required to revisit and collect data for the exact same site. When assessing the damage produced by natural calamities like floods, cyclones, earthquakes, and landslides that are impossible to access during such times, satellite photos with their ability to repeatedly revisit the same places are highly helpful. When planning relief and rescue activities, satellite photos are a great resource because they quickly and accurately give information about the disaster-affected area. They are helpful in choosing locations for storm and flood shelters. The scope of the devastating flood event's damage is plainly visible in the comparison of pre- and post-images.

Satellite images serve as the "eye in the sky" and provide essential visual evidence for monitoring the polar ice caps. These images offer unequivocal evidence of the dramatic changes occurring in the polar areas or the widespread retreat of numerous glaciers as a result of rising temperatures. Similar to this, satellite images also show how deserts are encroaching into previously deserted areas, as well as how widespread deforestation and forest fires, which frequently compel governments and environmental organizations to take necessary action. Satellite images have a huge range of applications and benefits. They have shown to be a stable and cost-effective technique of obtaining crucial information for analysts, planners, and decision-makers to track the world for the benefit of all humanity [xiii].

Remote sensing (RS) is a field of study that uses electromagnetic radiation as an interaction medium to identify features on the Earth's surface and estimate their geo-biophysical characteristics. With its synoptic view of the Earth's features, regular repetitive coverage over wide areas, and digital mode of data capture, satellite remote sensing provides an efficient way to map, monitor, and manage land resources and environmental impacts in close to real-time, as well as a historical profile for monitoring the Earth's features. By detecting energy transmission from the surface in various regions of the electromagnetic spectrum (EMS), satellite sensors can gather data on the Earth's surface.

The visible, near-infrared, middle-infrared, and shortwave infrared regions of the electromagnetic spectrum are where the optical remote sensing equipment operates. These instruments are sensitive to wavelengths between 300 nm and 3000 nm. The sensors, which work in the electromagnetic spectrum's thermal region, capture energy emitted from Earth features in the wavelength ranges of 3000-5000 nm and 8000 nm–14,000 nm. A microwave remote sensor captures the electromagnetic spectrum's backscattered microwaves with wavelengths between 1 mm and 1 m. Earth scientists can create geographic databases on natural resources for several uses using a wide range of satellite remote sensing data from the Moderate Resolution Imaging Spectroradiometer (MODIS), Landsat, IRS-IC, IRS-ID, IRS-P6, Cartosat-1, Cartosat-2, QuickBird, and Google [xiv].

Disaster remote sensing satellites, aircraft, or unmanned aerial vehicles (UAVs) help collect data for access and disaster management in real-time, monitor the environment, and damage to infrastructure, and aid in recovery including both artificial intelligence (AI) and machine learning (ML) change detection algorithms. These apps include Disaster Recovery, Earthquake, Emergency Management, Search and recover, Monitor weather patterns, Flood Rating Drought forecast, Reconstruction, Danger area, Mapping emergencies, and risks [xv]. Through the remote sensing device, the satellite images captured can be classified using any of the cloud computing platforms that has support for machine learning models that perform image classification using any of the Popular Classification Algorithms like Logistic Regression, Naive Bayes, K-Nearest Neighbors, Decision Tree, Support Vector Machines. The output of the of the Signal processing and early warning stage is then fed into the Monitoring system. The component monitoring part of this block is the **IP Address or the Domain name.**

Disaster Area

The same satellite image for the signal processing and early warning block is also used to pinpoint an exact location of natural disaster and level of impact and it helps in planning rescue operation and provision of relief materials. The output of the block is fed into the Monitoring system block. The component monitoring part of this block is the **IP Addresses or the Domain names of the signal for Signal processing and Early warning stage block**

The Monitoring system

The monitoring system will be a mobile device with the capability of sending news feeds across major social media sites. It will have the ability to make phone calls, send MMS and SMS. It must have ability to be configured with IP Address. A high-Tech Mobile phone can be used as monitoring device.

Information Dissemination

This block consists of all major social media platforms, it will get its input from the monitoring system. It will come as news feed into various social media platforms. The component monitoring part of this block is the **IP Addresses or the Domain names of various social media platforms.** The block will receive information on early waring as well as actual natural disaster when it finally occurs. Information on safe zones and how to access relief materials will also be provided.

Response from 911, Fire service and Hospital

The response and Emergency teams comprising of people from 911, Fire Service and Hospital will get their input from the Monitoring system. The component monitoring part of the above listed agencies will be their corresponding **phone numbers**.

IV. Limitation

The major limitation of the design is cost of implementation, despite providing the needed solution, when cost of implementing a design is extremely high it becomes a major challenge.

High Resolution Satellite Image Pricing

Type of Satellite Imagery	Price in USD Archive - > 90 days	Price in USD for Priority Tasking
0.3 -1.5 m Resolution Stereo High Resolution Satellite Imagery	USD 16 to USD 48 per km2	USD 28 to USD 112 per km2 (minimum area of 100 km2)
Sub Meter Mono High Resolution Satellite Imagery	USD 4.50 to USD 24 per km2	USD 28 to USD 56 per km2 (minimum area of 100 km2)
1-3 m Resolution Mono High Resolution Satellite Imagery	USD 1.80 to USD 4.5 per km2 (minimum area of 100 -500 km2)	USD 8.65 to USD 13.5 per km2 (minimum area of 100 -500 km2)

(Pricing credit: Derived from Apollo Imaging)

[xvi] **Fig 5: High resolution satellite image pricing**

V. Conclusion

Catastrophe monitoring, early detection, forecasting, loss assessment, and effective analysis of disaster reduction are all necessary components of a complex iterative process for disaster management. Technologists and a variety of geographic information resources, including as sensors, data sources, models, geo-tools, software programs, and computing resources, are often used in conjunction with each activity. However, the majority of current disaster management systems function in a typical passive data-centric mode, which limits the use of resources. The complexity of application needs and the expansion of the variety of resources available are helping to address this barrier in some cases [xvii]. In this project, we have designed a comprehensive Disaster management system that uses high resolution satellites images to monitor the desired location in every ten minutes interval thereby providing 144 images for our classification and response to disaster areas.

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